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Investigating the Weaning Process in Past Populations

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ABSTRACT The 19th century St. Thomas' Anglican churchyard in Belleville, Ontario, Canada is associated with a large and well-preserved infant skeletal collection (n = 149) and good-quality parish records that document interments in the graveyard (1821–1874). By using a combination of historical demographic and stable nitrogen isotope analyses on the parish records and skeletal remains, respectively, a general pattern of extended nursing for about 14 months, introduction of foods other than breast milk by around 5 months of age, and variation in breast-feeding and weaning behaviours were detected for St. Thomas' infants. The results demonstrate that it is possible to go beyond the concept of weaning age to explore the weaning process in past populations when appropriate and large samples of documentary and skeletal data are available. Am J Phys Anthropol 105:425–439, 1998. © 1998 Wiley-Liss, Inc.

It is customary in the skeletal biology literature to discuss a phenomenon dubbed "weaning age" (Corruccini et al., 1985; Lanphear, 1990; Blakely et al., 1994; Katzenberg et al., 1996; Cucina and Iscan, 1997), an event that marks the complete cessation of breast-feeding. This approach is limited because it treats weaning age as though it were a single event that can be measured in a moment, rather than as a process that unfolds gradually as the infant matures in a given environment. In other words, it masks the complicated, variable, and often protracted process through which infant diets are transformed from breast milk to other foods through the introduction of non-breast milk food (Dettwyler and Fishman, 1992; Stuart-Macadam and Dettwyler, 1995; Katzenberg et al., 1996). In this study we demonstrate that it is possible to go beyond the concept of weaning age in past populations and explore the weaning process, the period between the introduction of foods other than breast milk and the cessation of nursing, when appropriate data are available for analysis. To the best of our knowledge, no other study has documented the probable duration of the weaning process in a past population, except for a few studies in which information on breast-feeding patterns was gathered on then-living populations (cf. Knodel and van de Walle, 1967; Knodel and Kintner, 1977; Kintner, 1985).

The focus of this research is St. Thomas' cemetery, an Anglican churchyard in Belleville, Ontario, Canada used for interments from 1821 to 1874. The project and history of the town have been described thoroughly elsewhere, and interested readers are referred to those sources for details (cf. Herring et al., 1991; Saunders et al., 1991, 1994, 1995; McKillop, 1995). Briefly, in 1989 during the course of an archaeological excavation of about one-third of the original church-

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yard's expanse, a total of 604 individuals were identified in grave shafts. Among these were the remains of 149 infants, some having been interred with their mothers. Over and above this relatively large sample for skeletal biological research, parish records for St. Thomas' Anglican church were maintained throughout the 53 years of the churchyard's use, documenting in some detail the interments of 292 infants. This wealth of skeletal and documentary evidence offers the opportunity to illustrate the importance of using overlapping data sets as cross-checks against each other and as complementary sources of information, and to use several methods to explore breast-feeding practises and the weaning process in a historic population.

MATERIALS AND METHODS

Here we apply two methods for evaluating nursing and weaning to the parish records and skeletal remains from St. Thomas' cemetery. The first, the biometric model (Bourgeois-Pichat 1946, 1951a,b, 1952), is a demographic method for distinguishing breast-feeding from non–breast-feeding populations and for inferring weaning patterns from the age distribution of documented infant deaths derived from sources such as parish or civil registers (cf. Knodel and Kintner, 1977; Sawchuk et al., 1985). The biometric model can also be applied to the age distribution of infant deaths derived from skeletal remains (Saunders et al., 1995; Stuart-Macadam, 1995). The second, stable isotope analysis, can be used on the organic fraction of bones or teeth in skeletal samples. We have been unable to locate any other research that employs the two methods in a single study. Our initial interest in experimenting with these two methods centered on comparing the extent of agreement in the results from each and determining if, in combination, they provide more information on breast-feeding and weaning patterns than either does alone.

The biometric model and St. Thomas' parish records

In several articles published almost half a century ago, Jean Bourgeois-Pichat (1946, 1951a,b, 1952) developed a demographic method for partitioning the infant mortality rate into endogenous (causes of death influenced by conditions before or during birth) and exogenous components (causes of death influenced by the quality of the postnatal environment). The initial intent of the model was "to circumvent by arithmetic means the inadequacies of the basic cause-of-death data" in documentary sources, which often lack sufficient precision for distinguishing endogenous from exogenous causes of death (Logan, 1953:60).

The model is based on the hypothesis that there is a stable and invariant linear relationship between age and cumulative infant mortality rates between 1 and 11 months of age, once a natural logarithmic function: $[\log(n + 1)^3]$ has transformed age in days, where n = age in days (Bourgeois-Pichat, 1951a:243). In this model, the *distribution of ages at death during the 1st year of life* is important, not the overall level of infant mortality:

> La structure par âge de la mortalité de un à onze mois est à peu près indépendante des variations de cette mortalité, qu'il s'agisse de variations dans le temps ou dans l'espace (Bourgeois-Pichat 1951a:240).

Demographers and medical researchers have applied the biometric method to infant mortality data from a variety of contexts, both historical and contemporary (see London, 1993, Galley and Woods, in press). These studies have shown that the postulated linear relationship between log-transformed age in days and cumulative infant mortality breaks down under certain circumstances. One pattern of deviation from the expected linear relationship has been observed when cumulative mortality during the second 6 months of age rises less sharply than would be expected from a straight line relationship with log-transformed age in days. Bourgeois-Pichat (1951a:345) noted just such a pattern for Quebec, Canada (1944–1947), arguing that advances in medical technology in the mid-20th century had altered the age structure of infant death, delaying the demise of some children past their "scheduled" earlier age at death and saving the lives of some who otherwise would have died in the 1st year life.

A more commonly observed deviation from linearity is found in populations where sani-

tary-social conditions are poor and where a high proportion of infants either are not breast-fed or are weaned at an early age onto nutritionally inadequate or contaminated foods. The transition from a breast-fed to a mixed food diet, if it occurs too early in the infant's life, tends to be associated with increased risks of the weanling diarrhea syndrome and food allergies. The infant's immature digestive and immune systems are forced to cope with food-borne and other pathogens, while the infant simultaneously risks malnutrition as maternal milk production falls off in association with fewer and less intense nursing bouts (Hendricks and Badrudin, 1992). Under such circumstances, cumulative infant mortality tends to be higher in the second half of the 1st year of life than is predicted by the linear model. A point of flexion is often observed around 2–4 months of age, and the slope of the line representing cumulative infant mortality is relatively steep thereafter (Knodel and Kintner, 1977:393).

Knodel and Kintner (1977) explored the properties of the biometric model in an important article which focussed on the relationship between the age structure of infant mortality and breast-feeding behaviour. Their study involved re-analysing published data from five historical studies of infant mortality for which information on infant feeding patterns was available (Woodbury's data for 8 U.S. cities [1911–1916]; Prinzing's information for Berlin [1895–1896], Barmen [1905], Cologne [1908–1909], and Hannover [1912]). The data were used to examine the effects of "artificial feeding" (their term), breast-feeding, and weaning on the age structure of infant mortality in these populations. Their results, redrawn in Figure 1a and 1b, confirmed that there is a close relationship between the type of feeding and the cumulative age structure of infant mortality.

Briefly, they found that in populations in which breast-feeding was rare or only practised for a short period of time (Fig. 1a), cumulative infant mortality rose more steeply than expected in the early months of life. Under these circumstances the ratio of the slope of the line between 6 months and 1 year of age, compared to the slope of the line between 1 month and 6 months of age, was less than unity (Table 1). Among populations with extended breast-feeding, in contrast, a gradual increase in cumulative infant mortality was observed in the first 6 months of life, followed by a steeper slope in the latter half, as the immuno-protective effects and nutritional benefits of breast-feeding diminished (Gordon et al., 1990; Jeliffe et al., 1989) in concert with the introduction of other foods. Under these circumstances, the ratio of the slopes exceeded unity. Finally, when age at weaning was controlled, the line describing cumulative infant mortality showed a sharp rise following the cessation of breast-feeding.

In this way, Knodel and Kintner (1977) showed that the age structure of infant mortality, when transformed according to the biometric model, conveys information about breast-feeding practices, the onset of the weaning process, and the quality of the sanitary-social environment in which both occur.

The validity of patterns of infant feeding inferred via the biometric model is predicated on the accuracy of the estimates of age-at-death. Previous analyses of infant mortality at St. Thomas' suggest that infant deaths were under-enumerated, especially during the early decades of the cemetery's use. Both neonates (<1 month) and postneonates (1–11 months) appear to have been significantly under-represented during the 1820s and 1830s (Herring et al., 1991). This phenomenon probably reflects the small population of the town at the time and the rural nature of the parish during its early years, increasing the likelihood that infants would be buried in family farm plots rather than in town. The improvement in the representation of infants in the burial sample from the 1840s onward may, in turn, not only be related to increasing urbanization in the region but may also stem from a transformation in attitudes to death, particularly toward the death of children, which is reflected in new mortuary practices and the rise of the public funerary industry in the 19th century (see Bell, 1990; Cannon, 1995; McKillop, 1995).

Given the potential distorting effects that under-enumeration could have on the age

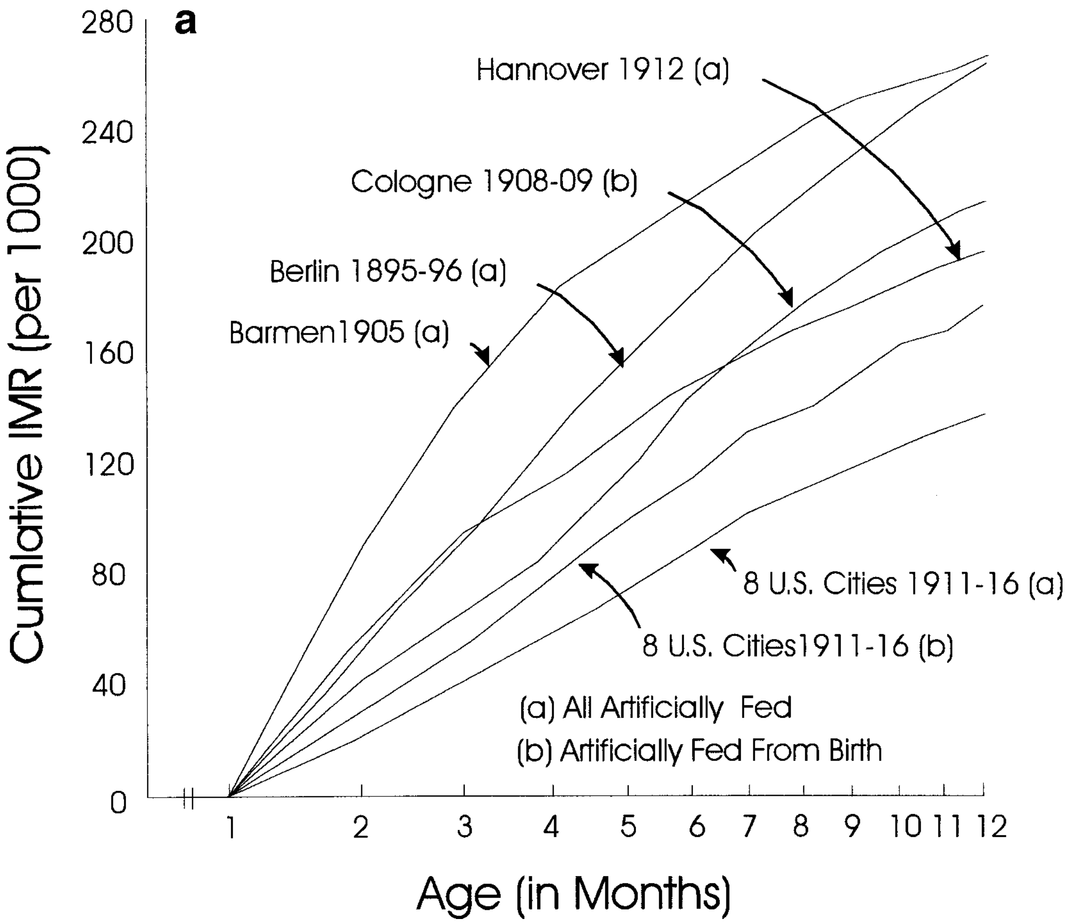

Fig. 1. Cumulative infant mortality from 1 month to 1 year of age by type of feeding. **a:** Artificial feeding (Knodel and Kintner's term). **b:** Breast-fed. Redrawn from Knodel and Kintner's (1977:397) graph of Woodbury's (1925) data for eight U.S. cities (1911–1916) and Prinzing's (1931) information for Berlin (1895–1896), Barmen (1905), Cologne (1908–1909), and Hannover (1912).

structure of infant death, we scrutinized St. Thomas' baptism and burial registers for sources of bias. The likelihood of under-enumeration of infant deaths increases when the interval between birth and baptism is long. When baptisms are not carried out soon after birth, the possibility increases that young, sickly infants will die unbaptized, and possibly without the burial rites of the church. Analysis of St. Thomas' registers shows that the average interval between birth and baptism for the entire period (1821–1874) is quite long, with a mean delay of 122 days, or approximately 4 months (Table 2).

Yet, there is evidence that families made efforts to baptize imperiled infants. Almost one-half of the 384 records of private baptisms are accompanied by remarks indicating that the infant was sick or died shortly after baptism. Interestingly, private baptisms increased significantly over the study period from 6% in the first decade (1821–1829) to 21% in the last years of the churchyard's use (1870–1874). At this point, it is not possible to gauge whether this is a reflection of the rising risks of infant death over time or merely a change in fashion in burial ritual at St. Thomas' (McKillop, 1995), or both.

Illegitimate births, another common source of under-reporting, are also mentioned in the baptism registers. Twenty ille-

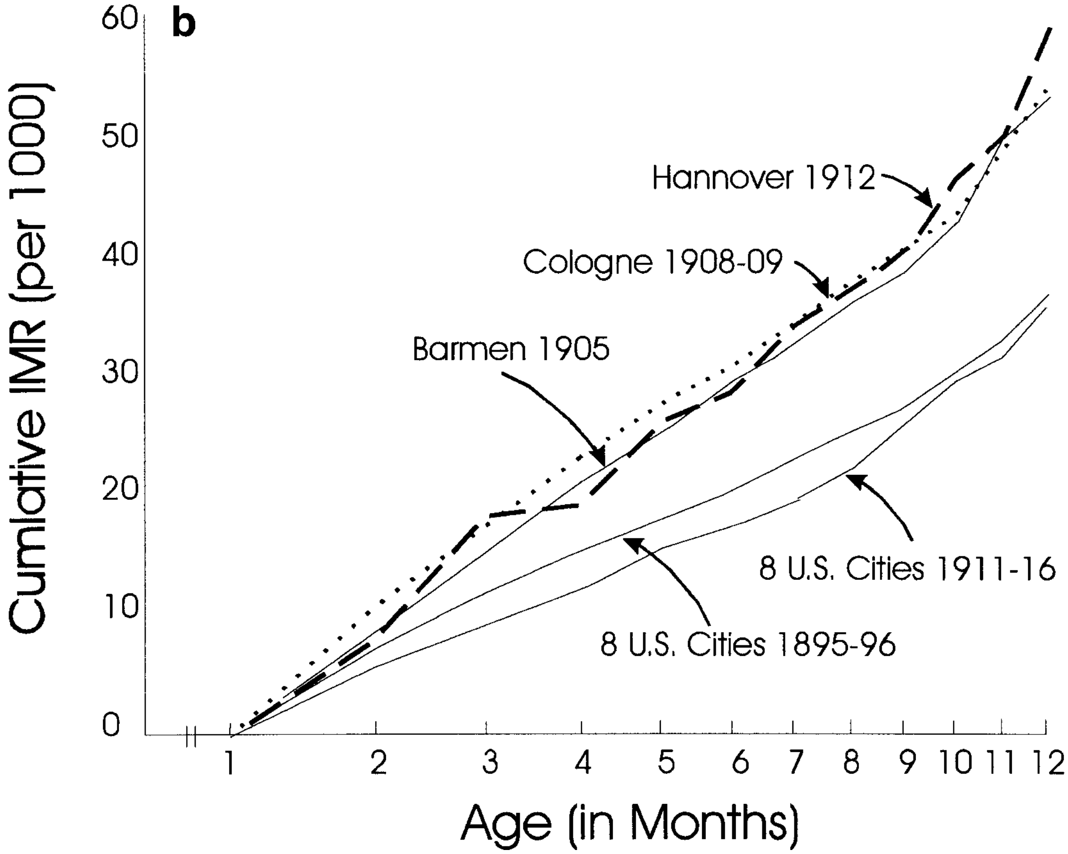

Fig. 1 (continued)

gitimate babies were baptised between 1821 and 1874. This results in a low ratio of illegitimate to legitimate baptisms of less than one (.48), but without estimates of the prevalence of illegitimacy in the town, we are unable to evaluate the significance of the ratio for the accuracy of St. Thomas' registers. Illegitimacy ratios vary dramatically in time and space, and low illegitimacy ratios of one to two occurred at various times in history (Drake, 1974:79).

The critical issue for the Bourgeois-Pichat model, however, is precision in the age structure of infant death. To control for potential inaccuracies in the age-at-death information introduced through under-enumeration, we eliminated from the sample infant

TABLE 1. The ratio of slopes of lines determined by the biometric analysis of infant mortality, by type of feeding, using data from Woodbury (1925) and Prinzing (1931)[1]

			Artificial feeding	
Study area	Date	Breastfed	All infants	Since birth
U.S. cities	1911–1916	1.63	0.83	0.82
Berlin	1895–1896	1.25	0.72	—
Barmen	1905	1.28	0.37	—
Cologne	1908–1909	1.18	—	0.73
Hanover	1912	1.37	0.47	—

[1] From Knodel and Kintner (1977:398).

TABLE 2. Location of baptismal ceremonies by decade, St. Thomas' Anglican Church, 1821–1874

	Private		Church		
Decade	N	%	N	%	Total
1821–1829	22	5.6	371	94.4	393
1830–1839	12	2.7	430	97.3	442
1840–1849	55	4.9	1071	95.1	1126
1850–1859	111	11.6	849	88.4	960
1860–1869	123	13.1	818	86.9	941
1870–1874	61	21.0	230	79.0	291

baptisms and burials that occurred prior to 1840, the period for which under-reporting is most evident in the burial register. To control for misreporting of ages at death, we further limited the analysis to infants whose burial record could be linked, either by name or through genealogical details contained in the parish records, to a baptism record. Likelihood ratio chi-square analysis revealed that there were significantly more post-neonatal deaths (≥28 to <365 days) among unlinked than linked infant burials ($\chi^2 = 7.25$, $P = .007$, df = 1), the net effect of which would be to weight the distribution of ages toward older infants without there being any certitude that the ages were correct. This problem was circumvented by including in the study only those infants whose ages could be verified. We used the total baptisms (n = 3,040) from 1840 to 1874 as the denominator for the infant mortality rate computations. This results in an underestimate of the rate of infant death because the numerator represents only a sample of recorded infant burials while the denominator represents all baptisms during this period; however, it is the *age-specific pattern of infant mortality* that is important in Bourgeois-Pichat's biometric model, not the overall level of infant mortality. The ratio of slopes stays the same regardless of whether the denominator is, say, 700 or 8,000. This is one of the properties of the model that makes it so useful for exploring breastfeeding and weaning patterns in large, accurately aged samples of infant skeletons.

In sum, the biometric analysis presented here is based on a carefully controlled sample of 188 infants buried in St. Thomas' churchyard between 1840 and 1874 for whom the exact age at death has been determined through record-linkage.

Age estimation of infant skeletal sample

A total of 282 subadult individuals were initially identified in the skeletal sample on the basis of active tooth eruption, skeletal epiphyseal development, and fusion. Tooth formation was evaluated in those cases for which developing teeth were observable in panoramic and lateral radiographs. The developmental stages for tooth crown and root formation proposed by Moorrees et al. (MFH) (1963a,b) for the permanent mandibular and three deciduous canine teeth were determined for all present and observable teeth. Interpolation charts for the mean dental age of each tooth were prepared from the norm charts published by Moorrees and colleagues (Moorrees et al., 1963a,b). Overall mean dental age was then calculated for each individual based on the available permanent and deciduous forming teeth. Details of the methodological procedures and rationale are published in a study by Saunders and colleagues (1993). From these dental age estimates a sample of 89 infants estimated to be under 1 year of age at the time of death were identified. In addition, a further sample of 25 of the youngest individuals had their tooth development checked against three further sources (Prahl-Anderson and Van der Linden, 1972; Fasekas and Kósa, 1978; Deutsch et al., 1985) in order to judge whether they were too young to have been born alive and were likely stillborn. In all cases, age estimates were very close to newborn. Obviously, it is difficult to judge whether an infant from an archaeological site was stillborn. While the presence of a neonatal line in forming enamel may help (Skinner and Dupras, 1993), a liveborn infant could die before sufficient enamel was produced to form a line. While several infants judged as newborns were found buried beside their mothers, burial circumstances still do not allow a decision as to whether the infant was born alive.

Finally, the remainder of the subadult sample which could not be dentally aged (41/282) had their ages estimated on the basis of the lengths of the long bone diaphyses. Of the 41 cases, 35 were estimated to be infants under 1 year of age. The ages at death for all 149 infants were recorded in months.

Nitrogen stable isotopes from bone samples

Stable isotopes of nitrogen have been used routinely in paleodiet studies to differentiate consumption of marine and terrestrial foods (reviewed by Schwarcz and Schoeninger, 1991) and to evaluate trophic level (Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984) except in arid environments (Am-

brose, 1991). The realization that nitrogen isotopes could be used to evaluate nursing and weaning was presented by Fogel and colleagues (1989) in a study of nursing infants and their mothers. Following the demonstration that animals in successively higher trophic levels exhibit enrichment of ^{15}N relative to ^{14}N it was thought that infants feeding on mothers' milk might exhibit a similar enrichment. Fogel and colleagues analyzed fingernail clippings as a source of protein for their nitrogen isotope studies and documented an increase in $\delta^{15}N$ values as the infant nursed, then a decrease beginning at the time of weaning. $\delta^{15}N$ values returned to levels similar to those of mother shortly after breast-feeding stopped. These same authors then showed how a similar pattern of increasing, then decreasing nitrogen isotope values were exhibited in two skeletal samples (Tuross and Fogel, 1994; Fogel et al., 1989).

For these skeletal studies, they isolated the organic fraction of bone which is largely made up of the structural protein collagen. Subsequently, others have shown similar variation in $\delta^{15}N$ values in infants from various prehistoric (Katzenberg et al., 1993; White and Schwarcz, 1994; Schurr, 1997) and historic (Katzenberg and Pfeiffer, 1995) groups.

In this study, ribs were obtained from a sample of 60 individuals interred in St. Thomas' churchyard. The age distribution of the sample includes 20 individuals aged birth to 6 months, 8 individuals aged greater than 6 months to 1 year, 21 individuals aged greater than 1–2 years, and 11 individuals aged greater than 2–3 years of age. Individual ages and nitrogen isotope ratios are listed in Table 3. This sample was selected based on availability and attempted to maximize the number of infants and young children in the study.

Bone samples were cleaned ultrasonically then broken into small chips. The organic fraction was isolated following the procedure described by Sealy (1986). Following a soak in weak hydrochloric acid, bones were soaked in sodium hydroxide to remove humic contaminants. The remaining material which is largely collagen, was freeze-dried. Analysis of the samples for nitrogen isotope ratios was carried out on a Micromass Prism Mass Spectrometer in the Stable Isotope Laboratory in the Department of Physics, University of Calgary, under the direction of H.R. Krouse. Samples are first introduced into a Carlo-Erba gas analyser which provides quantitative data on the amount of carbon and nitrogen in each sample and in which N2 gas is isolated, then analysed by mass spectrometry. Precision of analysis is ±0.2‰.

A subset of these samples was analysed for amino acid composition. Fifteen samples were analysed on a Beckman 6300 amino acid analyser in the Protein Sequencing Facility of the Department of Medical Physiology, University of Calgary, under the direction of Dr. R. McKay. Carbon-to-nitrogen ratios provide a crude indication of the composition of the organic fraction recovered and should be between 2.9 and 3.6 (DeNiro, 1985). Amino acid composition provides a more refined look at the organic material recovered from bone. Here we test the hypothesis that subadult bones are less likely to be well preserved than are bones from adults. Differential preservation of specific amino acids may alter stable isotope ratios since individual amino acids differ in their isotope values (Hare et al., 1991).

TABLE 3. Nitrogen isotope ratios and age estimates from individuals aged newborn to 3 years

Age at death[1]	δ15N	Age at death[1]	δ15N	Age at death[1]	δ15N
0.00	10.0	0.81	12.7	1.81	11.3
0.00	11.1	0.85	13.2	2.00	11.1
0.04	12.7	0.94	12.8	2.15	11.8
0.15	10.7	0.97	12.2	2.17	11.2
0.23	11.6	1.01	8.2	2.35	11.3
0.25	13.1	1.03	10.6	2.38	9.3
0.25	11.3	1.04	12.3	2.40	10.3
0.27	13.2	1.05	12.1	2.46	10.0
0.27	11.9	1.05	14.8	2.50	9.6
0.27	11.1	1.07	13.9	2.52	10.1
0.28	12.7	1.08	14.6	2.53	11.0
0.31	13.6	1.14	12.5	2.59	9.9
0.31	11.8	1.18	12.4		
0.36	13.0	1.21	13.6		
0.38	11.8	1.25	14.0		
0.40	11.1	1.34	14.0		
0.51	9.3	1.36	13.8		
0.55	12.6	1.37	9.0		
0.57	12.2	1.42	10.4		
0.58	14.2	1.54	11.7		
0.64	13.2	1.57	9.5		
0.64	12.8	1.57	10.1		
0.65	13.2	1.58	12.5		
0.68	11.9	1.68	14.3		

[1]Ages used are mid-points of estimated age ranges.

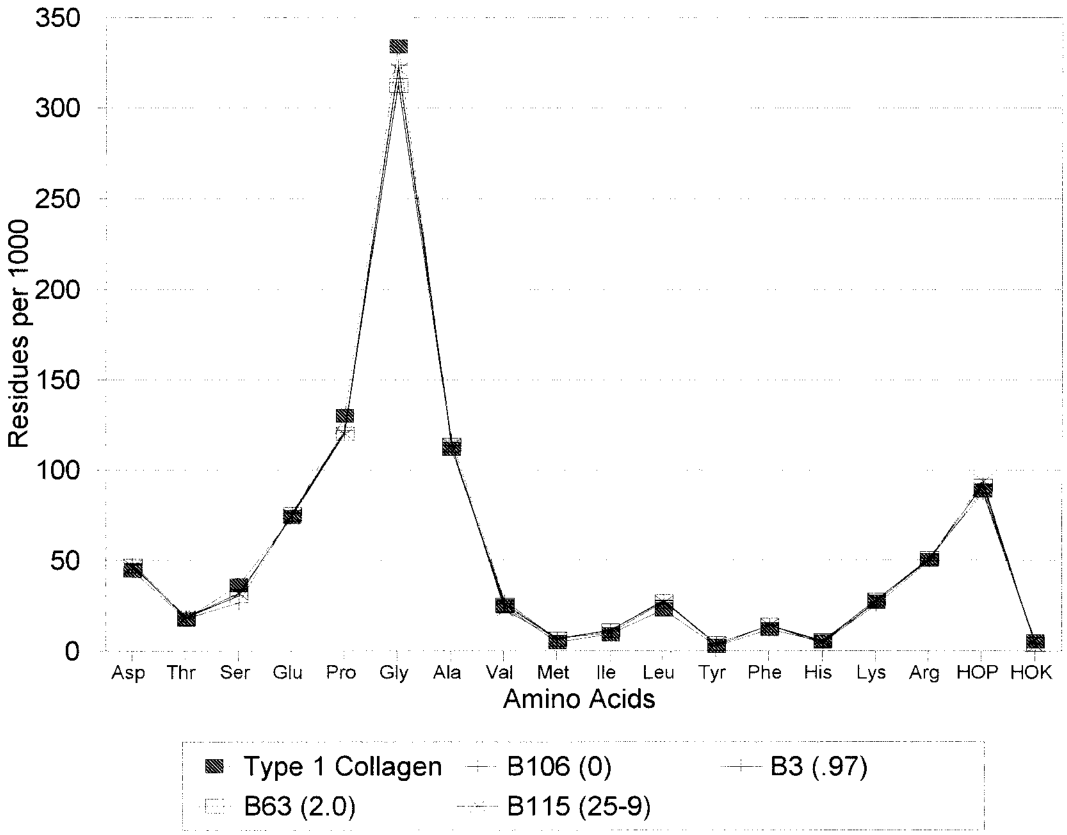

Fig. 2. Amino acid analysis (residues per thousand) for four burials compared to type 1 collagen (Bornstein and Piez, 1964). Burial numbers (B 106, 3, 63, 115) are followed by mean age, in parentheses.

All of the samples show well-preserved collagen, and no significant differences in amino acid composition were detected among any of the 15 samples. In Figure 2, the standard amino acid composition for collagen (in amino acid residues per thousand) is shown in the foreground of the graph along with four samples behind. They are, from front to back, two infants, a 2-year-old child, and an adult, for comparison. All of the samples shown (and all of those analysed) show the characteristic high peak of glycine, which makes up approximately one-third of collagen, and smaller peaks for hydroxylysine and hydroxyproline, amino acids found in collagen but in few other proteins.

RESULTS

When the biometric model was applied to the controlled sample of 188 linked infant deaths (1840–1874), comparable results were obtained to those found in a previous study of the full series of 292 infants with exact ages of death in St. Thomas' burial register (Saunders et al., 1995). Figure 3 shows the slope of cumulative infant mortality for the controlled series of infant burial records (solid ovals), all infants with an exact age in the burial register (open squares), and the infant skeletal sample (solid triangles) show a slight tendency to cant upward around 5 months of age, indicating excess mortality in the latter part of the 1st year of life, relative to the early months.

This was confirmed from the ratio of slopes analysis for the three series, shown in Table 4. All three ratio of slope values exceed unity, consistent with Knodel and Kintner's (1977) breast-feeding category. The two parish record estimates resulted in lower ratio

Fig. 3. Biometric method applied to record-linked infant deaths, 1840–1874 in St. Thomas' Anglican Church burial register (solid ovals). Comparison to all infant deaths with exact age in the burial register, 1821–1874 (open squares) and to all excavated infant skeletons, 1821–1874 (solid triangles) (Saunders et al., 1995:83).

of slope values (1.2 and 1.3) than were obtained for the skeletal sample, which yielded a value of 1.6 (Saunders et al., 1995). The higher ratio for the skeletal sample results from a larger proportion of infant deaths 5 months of age or older, relative to the two parish record samples. While this difference might be attributed to problems with age estimation in the skeletal sample, it most likely reflects simple random sampling effects in the skeletal series data. Even in a relatively large sample of infants like St. Thomas' the effects of small numbers are still evident for some age groups.

The pattern of deviation from linearity found for the two burial record samples and the skeletal series (i.e., the ratio of slopes exceeds unity) results from excess mortality in the last half of the 1st year of life, compared to the first half. The slight flexion in the line around 5–6 months of age found in all three samples suggests that breast-fed babies were being introduced to non-breast milk foods to such an extent by this age that cumulative infant mortality increased in association with the process. In all likelihood, this represents the classic weanling diarrhea syndrome where gastrointestinal disease associated with contaminated water and food combines with other contagious diseases to take a heavy toll of infants, many of whom are concomitantly exposed to the diminishing benefits of breast-feeding after 6 months of age or who have been weaned completely (Bourgeois-Pichat 1951a,b; Pressat 1972:96; Knodel and Kintner 1977; Gordon et al., 1990; Motarjemi et al., 1993). The citizens of Belleville were troubled by the poor quality of the water supply by the mid-19th century; with almost 40% of St. Thomas' infant deaths occurring during the hot summer months, this concern was clearly justified (Herring et al., 1991; Saunders et al., 1995). Studies of child morbidity impli-

TABLE 4. The ratio of slopes of cumulative infant mortality for St. Thomas' churchyard, determined by the biometric model: recorded and linked infant burials (1840–1874), all recorded infant burials (1821–1874), and all excavated infants (1821–1874)

Log-transformed age in days	Recorded and linked infant burials, 1840–1874			All recorded infant burials, 1821–1874			All excavated infants, 1821–1874		
	No. of deaths	IMR per 1,000	Cumulative IMR/1,000	No. of deaths	IMR per 1,000	Cumulative IMR/1,000	No. of deaths	IMR per 1,000	Cumulative IMR/1,000
313	59	19.41	19.41	79	18.51	18.51	39	17.91	17.91
576	18	5.92	25.33	26	6.09	24.61	3	1.38	19.29
757	14	4.61	29.93	23	5.39	30.00	13	5.97	25.26
908	14	4.61	34.54	26	6.09	36.09	21	9.65	34.91
1,039	10	3.29	37.83	14	3.28	39.37	10	4.59	39.50
1,154	17	5.59	43.42	26	6.09	45.47	7	3.22	42.72
1,259	12	3.95	47.37	23	5.39	50.86	13	5.97	48.69
1,355	16	5.26	52.63	20	4.69	55.54	10	4.59	53.28
1,443	10	3.29	55.92	18	4.22	59.76	7	3.22	56.50
1,528	5	1.64	57.57	13	3.05	62.81	13	5.97	62.47
1,607	9	2.96	60.53	14	3.28	66.09	7	3.22	65.69
1,685	4	1.32	61.84	10	2.34	68.43	6	2.76	68.44
Total died	188			292			149		
At risk	3,040			4,267			2,177		
Slope 1–6 mos.	0.029			0.032			0.029		
Slope 7–12 mos.	0.034			0.041			0.046		
Ratio of slopes	1.19			1.29			1.57		

cate contaminated weaning foods in diarrheal diseases/malnutrition to such an extent that "food safety is as important as breast-feeding or provision of safe water supplies and sanitation" for preventing them (Motarjemi et al., 1993).

The stable nitrogen isotope analysis also indicates that St. Thomas' infants were breast-fed (Fig. 4). The nitrogen isotope values of infants are significantly higher than those of adults. Overall $\delta^{15}N$ values range from 8.2 to 14.8‰ with a mean value of 11.1 ± 1.4‰. The mean $\delta^{15}N$ value for all individuals less than or equal to 2 years of age is 12.1 ± 1.5‰, while the mean $\delta^{15}N$ for individuals over 2 years of age is 10.4 ± 0.8‰ ($t = 7.7$, $P = .000$). A plot of $\delta^{15}N$ values fitted with a distance weighted least-squares curve (Fig. 4) shows a similar curve to that of previous studies (cited above) in which the trophic level shift associated with nursing is demonstrated. While nursing infants are feeding from mother's tissues in the form of milk, their $\delta^{15}N$ values increase and peak before other foods are introduced, whereafter $\delta^{15}N$ values decrease. What we cannot determine using this method is the lag time between changing diet and the reflection of that change in bone collagen. The drop in $\delta^{15}N$ values in this study is similar, around 1 year of age, to that seen in the infants from a nearby Methodist cemetery, also from the 19th century (Katzenberg and Pfeiffer, 1995).

It can be seen from Figure 4 that some infants and young children have $\delta^{15}N$ values which are not elevated relative to those of adults in the sample. One individual who presumably died during the perinatal period has a value of 10‰ and one individual aged to about 6 months of age has a value of 9.3‰. Elevated $\delta^{15}N$ values reflect the consumption of breast milk so they are not expected in newborns. Collagen laid down after birth should begin to reflect diet after birth. From the data presented here, that seems to be as early as 3 months of age. Six individuals aged from 1 year to about 1½ years also fall lower in the distribution, around the adult mean. This suggests that they were not breast-fed or stopped nursing earlier than the majority of individuals examined here.

The problem with using bone from infants who died is that we do not know if the cause of death was related to food (e.g., malabsorption problems, metabolic disorders) or the ability of their mothers to provide milk (e.g., death due to childbirth or related complications). Newer developments in mass spectrometry, such as the use of a laser probe to target a specific part of a sample, could be used to analyse nitrogen contained in dentin or enamel (Pillinger, 1992). This may circum-

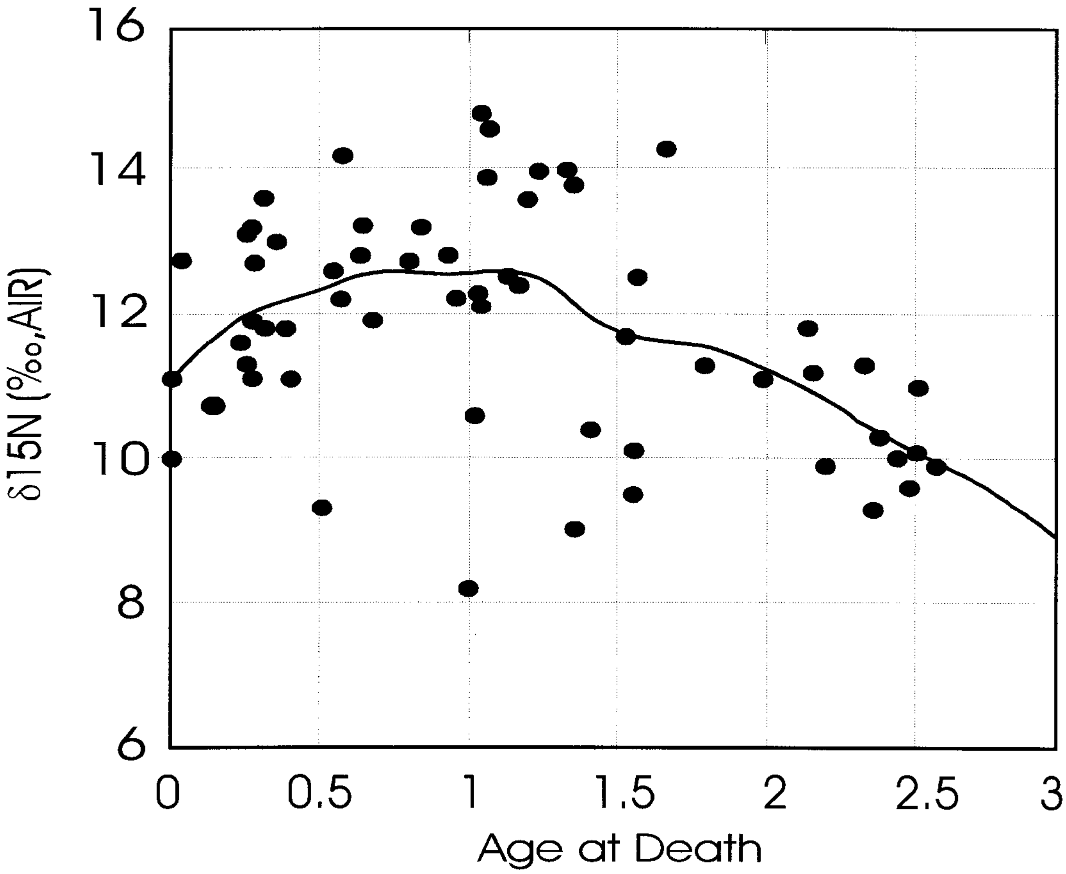

Fig. 4. Nitrogen isotope ratios (from Table 3) by age for St. Thomas' subadults aged newborn to 3 years ($n = 60$) with distance weighted least squares curve indicating trend in isotope ratios.

vent the problem of cause of death by allowing isolation of tissue that was formed during the first year of life from individuals who survived to adulthood.

Since the rate of collagen deposition and turnover in developing bones is not known at this time, it is impossible to determine precisely the time lag from cessation of nursing to a drop in $\delta^{15}N$ values. Presumably as other foods are introduced into the diet and as nursing decreases, the incorporation of amino acids from milk is being replaced by the incorporation of amino acids from other sources of protein. Thus we would expect to see a gradual decrease in $\delta^{15}N$ if it were possible to follow an individual through his/her period of infancy and early childhood. This is possible if one uses hair or fingernails, but is not feasible using protein from bone. We do know that during the 1st year of life, growth in length increases by 50% and that birthweight triples. From the information available at this time one would expect a lag of a few months between a change in diet and a concomitant change in $\delta^{15}N$ in bone collagen, assuming normal growth and development. Schurr (1997) has tried to address some of these questions by analysing the metaphyses of long bones in an attempt to sample only recently deposited collagen. In any event, we are unable at this time to determine whether the children who show $\delta^{15}N$ permil values within the adult range were never breast-fed, were breastfeeding occasionally, or were weaned completely several months prior to their death.

DISCUSSION

The combined results of the biometric analysis of infant burial records (1840–1874) and the stable nitrogen isotope analysis of the skeletal sample from St. Thomas' cemetery confirms that a substantial proportion, probably the majority, of Anglican women breast-fed their babies. The biometric analysis suggests, however, that by about 5 months of age a sufficiently large number of infants were receiving enough foods other than breast milk that cumulative infant mortality increased relative to the early months. This phenomenon is perhaps best viewed as a very general threshold effect, rather than an exact point. The observed pattern, nevertheless, is in general accord with Fildes' (1995:120) description of the weaning process in post-18th century Europe; namely, infants were introduced to other foods before their teeth had begun to erupt and before their ability to sit up was well developed.

The stable nitrogen isotope analysis suggests that by about 14 months of age, most infants had ceased ingesting significant amounts of protein in the form of breast milk. The combination of parish record and stable nitrogen isotope data suggest that the dietary transition from breast milk to solid foods occurred over roughly a 9-month period, on average. Viewed another way, the data suggest a pattern of extended breast-feeding which lasted for about 14 months. This is similar to the 14-month breast-feeding interval found by Henripin (1954) for 18th century Quebec (cited in Nault et al., 1990). Although the St. Thomas' results cannot be directly compared to historic Canadian studies that use measures of fertility to detect breast-feeding, they are in line with studies by Nault and colleagues (1990) and Thornton and Olson (1991) who infer breast-feeding from an inter-birth interval of 18 months or more following the birth of a child who survived the 1st year of life.

It has become a truism that breast-feeding and weaning practices show extensive individual (maternal and child), class, temporal, regional, and cross-cultural variation (Kintner, 1985; Fildes, 1986, 1995; Dettwyler, 1987, 1995; van Esterik, 1995; Woolridge, 1995). Since we have no way of determining the actual proportion of breast-fed infants or the extent of variation in maternal feeding and weaning practices, the study results should be cautiously interpreted for what they are: approximations derived from a mortality sample. The individual stable nitrogen isotope values nevertheless suggest that at least one infant in the sample may not have been breast-fed and that for many, nursing continued well into the 1st year of life.

Can St. Thomas' estimates be confirmed from local documentary data? Unfortunately, there are no systematic data on breast-feeding behaviour comparable to those marshalled by Knodel and Kintner (1977). There are, however, sparse, anecdotal accounts of infant feeding practices in and around the town of Belleville in the 19th century. In a letter to his mother in June, 1853 William Hutton describes his daughter's difficulties nursing her first child:

> Anna was fast recovering strength, but has no nourishment for baby in the breast that supprated (sic). Little Fanny is, however, thriving very fast indeed and is a lovely child. We have a glass bottle for her like a breast, covered at the outlet with a cow's teat and supplied through a small moveable tube—an American contrivance that supplies here Mama's defect very nicely indeed. The milk is supplied gradually to the teat as baby sucks and never runs out nor comes except by suction. (Boyce, 1972:184)

There is also evidence that cow's milk was fed to children in the area. In 1838, physicians in the nearby Kingston area expressed concern about the quality of cow's milk and its effects on the health of children:

> A certificate, signed by nearly 50 of the most eminent physicians, has been lately published, declaring their belief that Milk is unwholesome when obtained from cows which are fed on distillery swill and kept in confined situations. If any thing can be discovered tending to make young children more healthy, it is fully worthy of attention. (Kingston Chronicle and Gazette, 1838)

Others chastised mothers for inappropriate breast-feeding. The tendency to blame mothers for supposedly improper breast-feeding [read ignorance] and for the poor health of their children is common elsewhere during this period (see Ball and Swedlund, 1996):

Most mothers think that mother's milk is mother's milk, whether it is generated in a scorched and scrofulous breast, or secreted in the glowing reservoir of health and vigor. We might as well say that the milk obtained from a diseased, stump-tail, swill-fed cow, is as wholesome and nutritious as that which flows from the fine vigorous animal that browses in the green fields, drinks from the pebbly brooks, and rests beneath the shadow of protecting trees.

A mother should be cool, comfortable, and healthful in body, and placid in mind, when she nurses her child. If she is not all these, she weakens and perhaps diseases her little one. Another fault is that mothers too often give too much milk and not enough water to their babies. Milk is a child's food, and not its drink. When a child worries after being fed, before striving to quiet it by putting it to the breast, touch its lips to a cup of cool water, and its instinct and the real wants will tell it which to partake of." (Belleville Intelligencer, 1862)

The available documentary evidence for the period suggests that both breast- and bottle-feeding occurred and that opinions differed on the merits of breast-feeding, as well as on the sorts of foods that ought to be fed to children. Such discrepant views undoubtedly contributed to variation in infant feeding regimens and in the timing and duration of the weaning process, detected in the St. Thomas' cemetery data, as well as to differences in the foods to which weanlings were introduced.

CONCLUSIONS

This study demonstrates that it is possible to go beyond the concept of weaning age and to explore the weaning process in past populations when appropriate data are available. Application of the biometric model and stable isotope method resulted in both general and specific information on breast-feeding and weaning behaviour for the 19th century churchyard associated with St. Thomas' Anglican Church. The analyses of mortality samples derived from parish records and skeletal remains depict both a general pattern of extended nursing and variability in breast-feeding practises that ranged from complete absence to prolonged breast-feeding well past the 1st year of life. The introduction to the infant diet of foods other than breast milk begins to be detectable by about 5 months of age. This is in keeping with current universal weaning recommendations that by 4 months of age, and not later than six months, the infant be gradually introduced to weaning foods (Hendricks and Badruddin, 1992:130). Breast milk remained the main source of protein in the infant diet in Belleville until about 14 months of life, substantially less than the two years of breast-feeding recommended for developing countries today (Hendricks and Badruddin, 1992:130).

It was possible to use the biometric model and stable nitrogen isotope analysis in this study because of the relatively large size of the skeletal and parish record series, excellent preservation of the skeletal remains, and documentary information on the exact age at death of the infants. Whether these methods can produce meaningful results for smaller skeletal series (see Hoppa, 1996) or collections lacking documentary evidence against which the results from the skeletal analysis can be compared and cross-checked (Stuart-Macadam, 1995) remains to be explored. But certainly this is a fruitful avenue for additional research if our understanding of biosocial phenomena in the past, exemplified by breast-feeding and weaning behaviour, is to become more comprehensive and sophisticated.

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